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ASYMMETRIES IN INCLUSIVE PION AND KAON PRODUCTION AT LARGE-X WITH A POLARIZED BEAM

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ABSTRACT

We propose to measure asymmetries in the inclusive reactions

$$p\uparrow p \rightarrow \pi^{\pm} + \text{anything}$$

$$p\uparrow p \rightarrow K^{+} + \text{anything},$$

using a transversely polarized beam and a liquid hydrogen target. The measurements would be made using the polarized proton beam proposed for the M-3 Beam Line, a multipurpose spectrometer consisting of analyzing magnets, multiwire proportional chambers, and gas threshold Ĉerenkov counters. The kinematic range covered by the experiments would be $p_{\perp} \lesssim 1.5$ GeV/c and $x = p_L^*/p_{max}^* \simeq 0.5 \rightarrow 0.9$. If sizeable asymmetries are found at low $p_{\perp}$, then the proposed apparatus could be used as a beam polarimeter for further experiments: part of this apparatus will be used as a polarimeter utilizing Coulomb scattering.

PHYSICS INTEREST

Measurements of inclusive pion production in p-p collisions with a polarized beam, $p\uparrow p \rightarrow \pi^{\pm}$+anything, have revealed sizeable asymmetries in these processes at $p_{lab}=6$ and 12 GeV/c.[1,2] These asymmetries seem to be energy independent, they increase with both increasing $p_{\perp}$ [in Fig.1, $u=(p_{inc}-p_{\pi})^2 \propto p_{\perp}^2$], and increasing x $(=p_L^*/p_{max}^*)$ of the scattered pion, and reach large values (30-40%) for $x \gtrsim 0.7$ (Fig.1). The presence of these large effects in inclusive reactions was rather unexpected, since it was thought that contributions from different inelastic channels would tend to cancel out, resulting in small asymmetries. Although there have been attempts to relate these asymmetries to those in backward pion-nucleon elastic scattering [2,3] at present there is no clear theoretical understanding of the origin of these effects.

We propose to measure asymmetries in the processes

$$p{\uparrow}p \rightarrow \pi^{\pm} + \text{anything} \qquad (1)$$

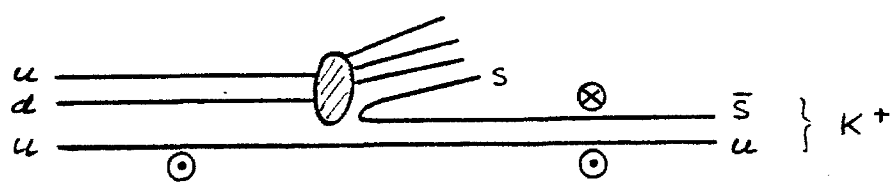
$$p{\uparrow}p \rightarrow K^{+} + \text{anything} \qquad (2)$$

at Fermilab energies with special emphasis on the high-x region. The experiment will utilize a transversely polarized beam, and thus we will measure the asymmetry

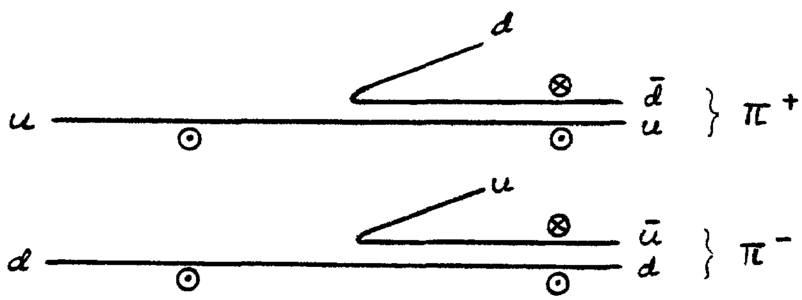
$$A_n(s,p_{\perp},x) = \frac{E\, d^3\sigma_{\uparrow}/dp^3 - E\, d^3\sigma_{\downarrow}/dp^3}{E\, d^3\sigma_{\uparrow}/dp^3 + E\, d^3\sigma_{\downarrow}/dp^3}, \qquad (3)$$

where $E\, d^3\sigma/dp^3$ is the invariant cross-section for particle production and $\uparrow,\downarrow$ refer to the transversity of the incoming proton.

We believe that the study of these processes may yield direct information about the constituent spin structure of the proton and about the spin dependence of the constituent-constituent interaction. Recent results from SLAC strongly indicate that the leading quark in high-x collisions carries the helicity of the proton.[4] If the leading quark carries also the <u>transversity</u> of the proton, and if pairs of quarks created in the strong interaction are polarized as seems to be indicated by the polarization in Λ production,[5] then high-x pion and kaon production should show significant single-spin asymmetries. In particular the process $p{\uparrow}p \rightarrow K^{+}$+anything



should select an $\bar{s}$ quark with opposite spin to the leading u quark (since the kaon is spinless) and thus with opposite spin to that of the incident proton. In fact, this asymmetry should equal the $\Lambda°$ production polarization times the fractional transversity remembrance at the same kinematic point, since the $\Lambda°$ polarization (s quark spin) is transverse. In addition, since the $\bar{u}$ and $\bar{d}$ polarizations should be identical



in creation from the vacuum, the π^+ and π^- asymmetries should reflect the transverse polarization retained by the high-x u and d quarks. Any deviation from this behavior would indicate incorrectness of this picture of high-x particle production, in particular that the leading quark is one of the valence quarks in the high-x meson, and/or that it does carry the transversity of the polarized proton. Thus this experiment is complimentary to the SLAC experiment which showed that the high-x quark carries the helicity of the proton. This experiment also affords an additional check on the mechanism for the observed large polarization in $\Lambda°$ production at FNAL and further generalizes these studies to all valence quark flavors in the nucleon.

In conclusion, we believe that measurements of the asymmetries of fast mesons produced in inclusive processes may be a very direct way of probing the spin dependence of the quark-quark interaction. In addition, if significant asymmetries are found at small transverse momentum, high-x meson production could be used as a convenient on-line monitor of beam polarization for all polarized beam experiments.

EXPERIMENTAL TECHNIQUE

The proposed layout of the experimental apparatus is shown in Fig.2.

The transversely polarized proton beam is incident upon a 100 cm long liquid hydrogen target. Since the beam originates from Λ decay, its divergence will be large ($\sim$1 mr). To obtain adequate resolution in $p_\perp$, the angle of each incoming particle is measured by the two x-y hodoscopes H1 and H2. The other hodoscopes H3, H4, and H5 will be used in the trigger. These hodoscopes will have a spatial resolution of 1.5 mm and will be spaced about 10 meters apart.

The production angles of charged particles emerging from the target are measured in the multiwire proportional chambers (MWPC) labeled PC1-PC6 as well as the hodoscopes H3-H5. Their angles, after magnetic analysis, are again measured in MWPC's PC7-PC10. The analyzing magnet shown is a standard BM109 (24VIII72).

For π^- production, particle identification is simple due to the opposite curvature of pions and protons in the field of the BM109. We plan to trigger only on π^- produced to beam left; thus, at P10 π^- are separated from the beam by .2-.6 m. Simply placing a scintillation counter (labeled C_{π^-}) as shown should provide a clean trigger for π^-. The π^- trigger will be tightened further by requiring the two threshold Ĉerenkov counters labelled Ĉ1 and Ĉ2, in coincidence. We expect to be able to make reliable estimates of π^- asymmetries on line.

For π^+ production, particle identification is more difficult, especially at very high values of x. We plan to use the two gas threshold Ĉerenkov counters in coincidence to suppress background from proton induced δ-rays from the beam and the copious inelastically scattered protons ($p/\pi^+=10^3$ at x=.9). Each counter should discriminate against protons at a level $<10^{-2}$; with the BM109 to sweep out delta rays produced upstream, we should get a total suppression of $10^{-4}\rightarrow10^{-5}$ of spurious proton triggers. The Ĉerenkov Imaging Detector (C.I.D.) shown in Fig.2. should further reduce this background. We expect singles rates $\sim10^5$/sec for each counter, but multiple coincidence trigger requirements should eliminate this problem. The Ĉ threshold setting along with the bend of the BM109 should strongly suppress background due to lower x pions ($p_{lab}\lesssim150$ GeV/c).

We plan to trigger the π^+ experiment by detecting deflection of scattered particles using the x-y hodoscopes H1-H5 and a hardwired coincidence matrix to suppress further spurious beam induced triggers. The hodoscopes have 1.5mm spatial resolution and each set, H1-H2, H3-H5, provides a lever arm of 10-20 meters. A deflection in particle trajectory of at least 0.2 mrad will be required to trigger the experiment corresponding to a cutoff $p_\perp\gtrsim .1$ GeV/c. Although this requirement introduces a bias against legitimate multiparticle events with a very small angle particle, we believe it is necessary for distinguishing very high x, small $p_\perp$ π^+ from protons, and that in fact, this small $p_\perp$ cutoff will negligibly bias the physics results. There should be $\lesssim 10^4$ trigger candidates/burst, so that a clean decision can be made by the matrix electronics with little deadtime.

The trigger for π^+ will therefore consist of deflection through an angle greater than 0.2 mrad. in coincidence with a count in both Čerenkov counters. The information from the C.I.D. will further discriminate against proton-induced background. For π^- the trigger will consist of the required bend in the BM109; i.e., a count in the C_{π^-}-counter and the coincidence of $\hat{C}1$ and $\hat{C}2$. This trigger can be further tightened by hodoscope requirements if necessary.

The identification of high-x kaons will be considerably more difficult, although we view this as a very important part of the experiment and will attempt to make this measurement if at all possible. We presently believe that neither threshold nor conventional differential counters will adequately identity 300 GeV/c K^+. We are thus planning to use a Ĉerenkov imaging device located downstream of the LH_2 of about 1.5 m in length. Although presently the feasibility of such devices is tenuous, we believe that in the next three to four years this or an alternative velocity discriminating detector must be successfully built because of the needs of many FNAL users. We thus hope that high momentum K^+ detection can be done at the tevatron. The apparatus as shown will simultaneously detect π^- produced to the left and π^+ and K^+ to the right with $x \to .5 \to .9$ and $p_\perp \lesssim 1.5$ GeV/c. At the higher values of $p_\perp$ discrimination of π^+ and K^+ from protons becomes less difficult due to the greater angular separation of the produced particles from the beam protons. We are particularly interested in investigating K^+ asymmetries out to a $p_\perp \sim 1.5$ GeV/c.

RATES, RESOLUTION, AND RUN PLAN

A summary of the expected rates and run time required to execute the initial parts of the experiment is shown in Table 1. The parameterizations of the inclusive scattering data by Johnson *et al.*[6] have been used for these rate estimates. With the initially expected intensity and beam polarization $I_o = 10^7$/pulse and $p_B = .4$, we should be able to measure asymmetries for $x = .5 \to .9$ in bins of .05 for ten bins of $p_\perp$ for $p_\perp < 1$ with an accuracy of $\Delta A \sim .03$ in the running time indicated for pion production. We expect to measure K^+ asymmetries up to $x \sim .8$ with errors $\sim .05$. We will also explore the region $1.0 < p_\perp < 2.0$ since the asymmetries here may be of most interest. We also request a tune up period which may be parasitic with low intensity beam on target; however, rates in the MWPC's and Čerenkov counters should be tested at $I_o \cong 10^7$/burst during the final stages of tune up.

We expect to use a BM109 shimmed to a 6" gap as the spectrometer magnet, giving a 1.2 GeV/c transverse deflection. The angular resolution of the upstream hodoscopes H1 and H2 determine the resolution $\Delta p_\perp \cong .04$ GeV/c, and the MWPC's give $\Delta x \cong \pm .03$.

Our resolution should enable measurement of the asymmetries in sufficiently small bins to determine the x and $p_\perp$ dependence. If no sharp structure is observed binning can be broadened to reduce statistical errors. Discrimination against spurious proton triggers and lower energy pions should ensure clean measurements of π^- asymmetries up to x=.9 and π^+ and K^+ asymmetries up to x=.8→.9.

We plan to explore quickly the high x, low $p_\perp$ region for possible large single spin asymmetries for pions. If these are found, the apparatus could then be used as a relative polarimeter for further beam tune-up. After the polarized beam is in stable operation, we then propose to explore the higher $p_\perp$ pion and the kaon production asymmetries. A summary of running time requests are as follows:

Tune up (mostly parasitic)	200 hours	
Low $p_\perp$	300 hours	700 hours
Higher $p_\perp$	400 hours	

If substantial asymmetries (∿.2-.3) are found, a polarimeter which measures $\Delta P_B/P_B$=.05 in ∿20 minutes can be effected with the same spectrometer.[7]

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TABLE I

Running Time Estimates

Reaction	Simultaneously Recorded Range $p_\perp$	Simultaneously Recorded Range x	I_o (ppp)	ΔA	Beam time (hours) 60 pulses/hour	
				10 bins of $p_\perp$ for $\Delta x = .05$		
$p\uparrow p \to \pi^+ X$	$.1 \to 1.0$	$.5 \to .85$	10^7	$.01/p_B$	120	simultaneously recorded
$p\uparrow p \to \pi^- X$	$.1 \to 1.0$	$.5 \to .9$	10^7	$.015/p_B$	300	
$p\uparrow p \to K^+ X$	$.1 \to 1.0$	$.5 \to .8$	10^7	$.02/p_B$	300	
				5 bins of $p_\perp$ for $\Delta x = .05$		
$p\uparrow p \to \pi^+ X$	$1.0 \to 1.5$	$.5 \to .85$	3×10^7	$.01/p_B$	400	simultaneously recorded
$p\uparrow p \to \pi^- X$	$1.0 \to 1.5$	$.5 \to .9$	3×10^7	$.02/p_B$	400	
$p\uparrow p \to K^+ X$	$1.0 \to 1.5$	$.5 \to .8$	3×10^7	$.03/p_B$	400	
				TOTAL REQUEST:	700 hours	

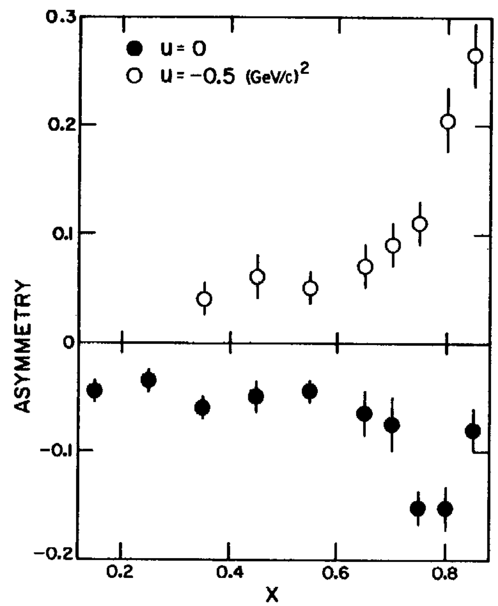

Fig.1a

The asymmetry for inclusive π^+ production from hydrogen at fixed u=0 and u=−.5(GeV/c)^2 as a function of Feynmann X. $u=(p_{inc}-p_\pi)^2$, so $u_{min}-u \tilde{\propto} p_\perp^2$. Here p_{inc}= 12 GeV/c.

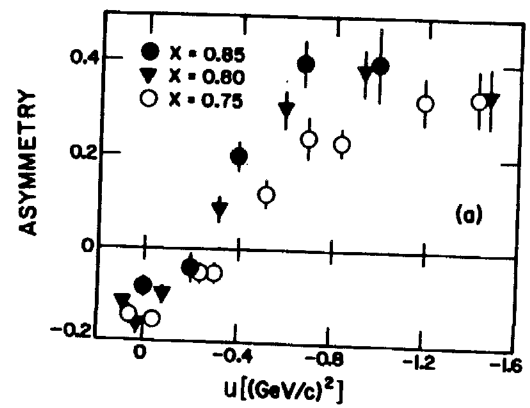

Fig.1b

The asymmetry for inclusive π^+ production from hydrogen at large x for p_{inc}=12 GeV/c. Increasing u corresponds to increasing transverse momentum.

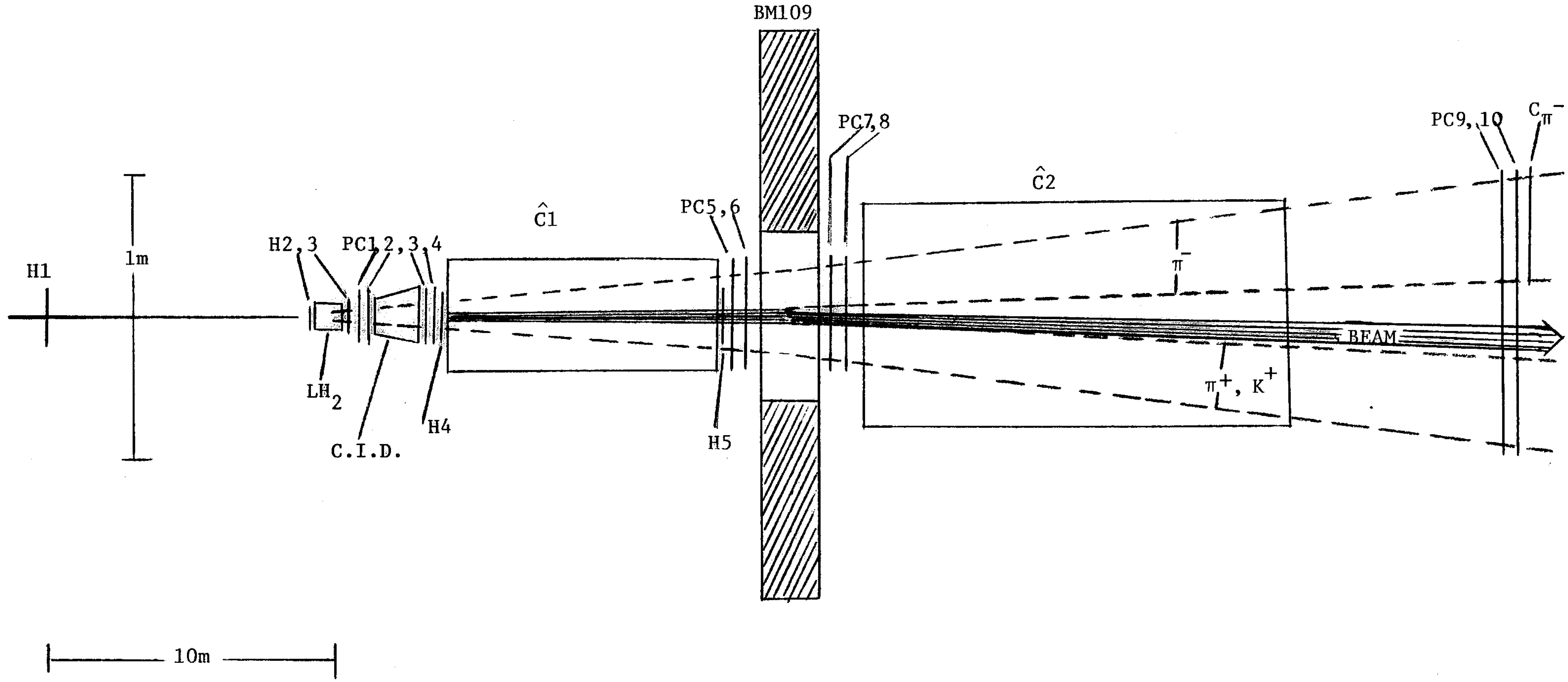

FIGURE 2

Proposed Layout of Apparatus